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Gaspard Lebel, Karel Kuypers, Raphaël Caire, Nouredine Hadjsaid, Stéphane Bediou, et al.. Domestic Demand Response for Primary Control support. CIGRE International Colloquium Lightning & Power Systems, May 2014, Lyon, France. hal-01021994

**HAL Id: hal-01021994**

**<https://hal.science/hal-01021994>**

Submitted on 9 Jan 2015

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# Domestic Demand Response for Primary Control support

Cigré International Colloquium Lightning & Power Systems - INSA de Lyon 2014, may 13rd

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**Abstract**—The following paper presents an agent-based platform, developed to perform locally fast load-shedding of domestic loads. The concept leads on frequency-based relays embedded into Customer Energy Management System (CEMS) and coordinated by remote servers, data concentrators or any devices compatible with the upcoming generation of Advance Metering Infrastructure. The platform enables to reproduce the droop curve that a bulk generation unit currently follow to provide Frequency Containment Reserves (FCR, ex Primary Reserve) to a System Operator. This droop curve can thus be used to support regular FCR or act as a pre regular frequency load shedding to avoid the curtailment of large parts of Distribution Network that might contain distribute sources, both renewables and conventional.

**Index Terms**—Virtual Power Plant, Demand Response, Ancillary Services, Distributed Frequency Control, Customer Energy Management System

## I. CONTEXT

### A. The opportunity of Demand Response automation

The concept of Demand Response (DR) or Active Demand (AD) can be defined as [1] the supply of an incentive to a power consumer, to stimulate him to switch from his business-as-usual load curve, toward a modified one, at the benefit of a given power system actor. This actor can be an aggregator, a producer, a retailer or a system operator. While several kinds of Demand Response services already exist [4], the penetration of ICT technologies in power system enables now to define new services, where each load is willing to react on a coordinated way to minute or even second-based incentives, for much stronger services supply.

### B. The benefit of fast Demand Response for the System Operator

An application enabled by ICT penetration is, among others, the supply of fast power margins, for frequency support purpose. The interest for the TSOs would be to replace the sudden emergency load-shedding mechanism by a smoother mechanism, willing to increase the Power System security of supply and even potentially to lead on fewer bulk generation units to operate their Primary Control mechanism, by calling

distributed control margins instead. The interest for the DSOs would be to complement the old fashioned emergency load-shedding mechanism which is currently activated in case of large frequency drop, by a distributed control which acts first only on non-vital loads. Mutual benefit for both includes the possibility to save from disconnection the Distributed Generators and thus avoid larger unbalance [3].

## II. CONCEPT

The fast frequency regulation proposed by Grenoble INP and Schneider Electric, leads on the combination of programmable frequency-based relays, and a coordination platform/agent able to define the shedding value of each relay, embedded in CEMS' devices, in a limited area of the system. The coordination agent can be hosted by either a remote server or a secondary substation's RTU, depending on the communication channel used. At the end, it constitutes an autonomous system willing to provide fast frequency containment margins to the utility in MW/Hz. Practically, this participation to the frequency reserve is enabled by the step-by-step shedding of hundreds of some kW loads, able to reproduce accurately the linear droop curve that a bulk generation unit usually follows.

## III. DEMONSTRATION

The validation of the concept has been done on Grenoble INP's PREDIS platform, by deploying coordinated energy boxes on a reduced scale power system.

### A. Field Test

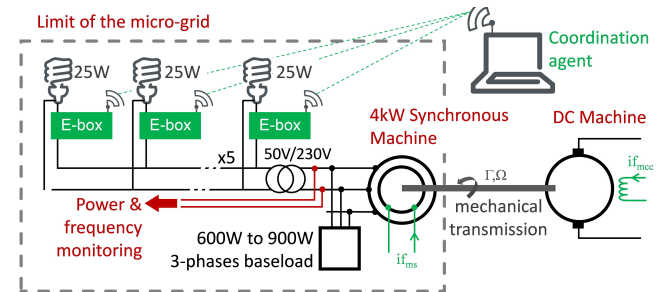


Fig. 1. Presentation of the agent-based platform and the field test

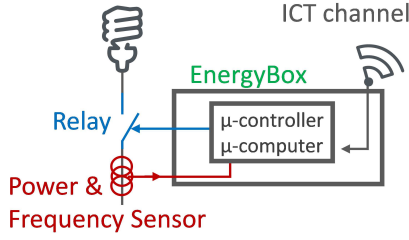


Fig. 2. Scheme of principle of the energy box developed

The field test is described in Figure 1. On the one side, it leads on 4kVA Synchronous Machine, operating as an alternator. This Synchronous Machine comes from the EDF analogical emulator representing dynamically at reduced scale the behaviour of a conventional thermal unit of the French power grid. On the other side, five dispatchable loads are connected to the grid and controlled by energy boxes. The energy boxes used (Figure 2), has been specifically developed for the demonstration, in order to embed the Java agents used for the coordination. A coordination agent is finally host by an independent computer, and communicates with the boxes by a local Ethernet network.

### B. Protocol of tests

The demonstration aimed to prove the ability of the agent-based distributed platform to provide a support to the grid with the same accuracy as a bulk generation unit can do. The use of a reduced scale power system fed by one generator has however imposed to adapt the protocol of tests. Indeed, it has not been doable to reproduce a blackout on the micro grid, given that the machine stays always able to stabilize the frequency at a lower value, regardless the amount of load suddenly connected to the grid (in a limit of 4kVA). Three kinds of tests have consequently been performed. The first ones aimed simply at showing the agent-based platform's ability to regulate the micro grid's frequency in steady-state situations. The second ones aimed at testing the energy boxes' time response face to a sudden frequency drop, while the third ones aimed at validating the respect of the droop line predefined.

### C. Results

The results of these three sets of tests are presented in the Figures 3 to 7 and detailed in the next section.

1) *Illustration of frequency stabilization in steady-state operation:* The validation of the concept in steady state operation was actually not planned initially, for two reasons: Firstly, the electric wave provided by the 4kVA generator can vary naturally of  $\pm 80mHz$  due to the machine's imperfections and the lack of inertia of the micro grid. Secondly, the natural slope of the micro grid's droop curve is comprised in a range of  $[1; 2mHz/W]$ . Thus the impact of a 25W load-shedding on the grid frequency cannot be really analyzed and used to assess the platform robustness. It has finally been decided to perform

some tests with a reduced droop curve of  $1.35mHz/W$ . The frequency and load curves are presented in Figure 3, while the frequency deviations with or without regulation are displayed in Figure 4.

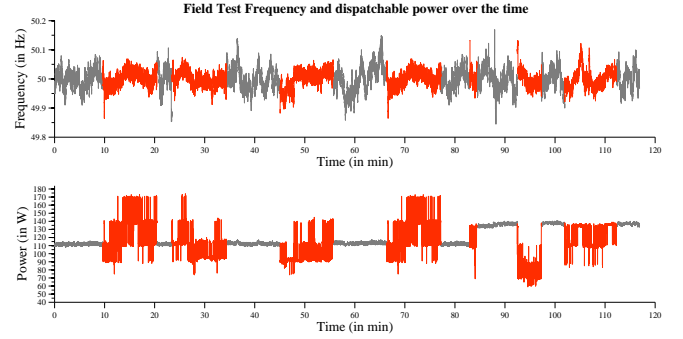


Fig. 3. Test of the agent-based platform in steady-state operation

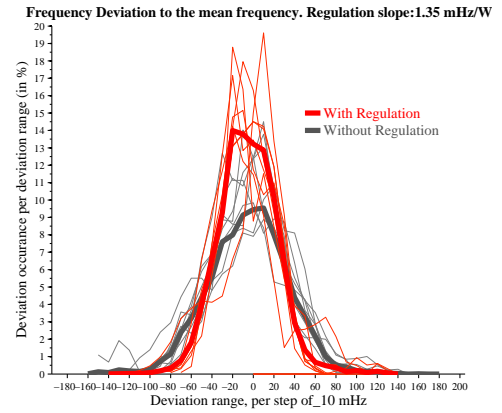


Fig. 4. Frequency deviation in steady-state operation

Despite these tests does not enable to validate the present concept, the results stays interesting and prove that the energy boxes' relays act fast enough to reduce the frequency deviation bandwidth.

2) *Validation of the agent-based platform time-response:* The Figure 5 displays the field test's response face to a sudden frequency drop engendered by the connection of a large load to the system. 27 tests have been performed, with or without the implementation of the regulation platform. The characteristic frequency and delay values obtained during these tests are summed up in Table I.

The results illustrate that the energy boxes effectively handle the frequency droop faster than the natural system behaviour: First, the frequency drop's depth  $\Delta F_d$  is reduced by 20% with the frequency regulation, while the rebound  $\Delta R_d$  stays of the same magnitude. Then, the mean delay  $\Delta T_d$  at which the frequency gap is obtained, passes from 1046ms to 872ms, i.e. is reduced by 17%. These both observations prove consequently the impact of the coordinated energy boxes on the system stability.

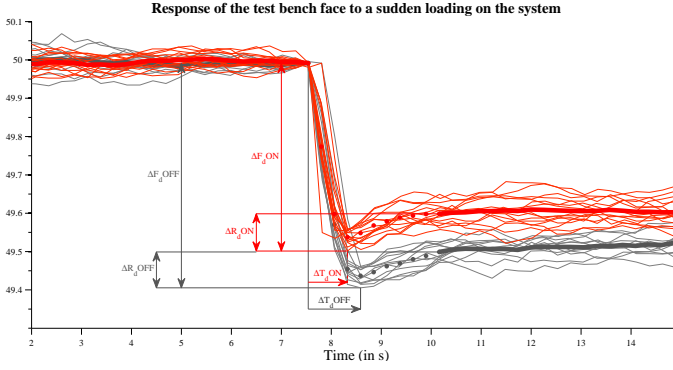


Fig. 5. Micro-grid response to a major outage, with and without frequency regulation

TABLE I  
FREQUENCY AND DELAYS VALUES OBTAINED DURING THE SUDDEN  
FREQUENCY DROP TESTS

		With Reg- ulation (ON)	Without Reg- ulation (OFF)
Number of tests		15	12
Frequency drop $\Delta F_d$ observed on the field test (in mHz)	Mean Drop	455	547
	Max Drop	514	584
	Min Drop	307	492
	Standard Dev.	50	29
Rebound $\Delta R_d$ observed on the field test (in mHz)	Mean Rebound	72	81
	Max Rebound	118	115
	Min Rebound	12	54
	Standard Dev.	28	17
Frequency drop delay observed $\Delta T_d$ (sampling period: 260ms)	Number of occurrences		
	785ms	11	2
	1045ms	3	8
	1310ms	1	2
	Mean Delay	872ms	1046ms

3) *Validation of the droop curve conformity*: The conformity toward the expected droop curve has been tested by modifying slowly the micro grid frequency, by acting on the Synchronous Machine speed. Eight cycles of frequency decreasing and rising have been performed over 12min. The Figure 6 displays then whole  $\{frequency; load\}$  values, monitored on the micro grid at a time interval of  $\approx 250ms$ . The red curve in stairs added above represents the mean droop curve applied by the coordination agent.

The switches from one step of the stair to the next one correspond to an energy box's relay opening or closure. The small load variations observed within a given step are due to a slight voltage variation on the grid. The values plotted in red represents the values which are actually out of the frequency bounds defined by the coordination agent. The out of bounds values represent 15.8% of the whole values monitored during the 12min test. The Figure 7 sorts finally these values depending on their distance to the frequency range where they should be included. The additional 5.4% of values (grey bar in Figure 7), having a deviation of less than  $\pm 10mHz$  are not considered as out of bounds values,

given that it corresponds to the energy boxes' precision.

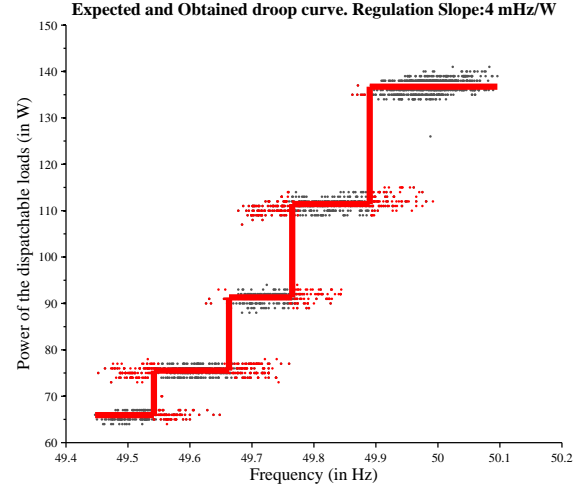


Fig. 6. Expected and obtained droop curve

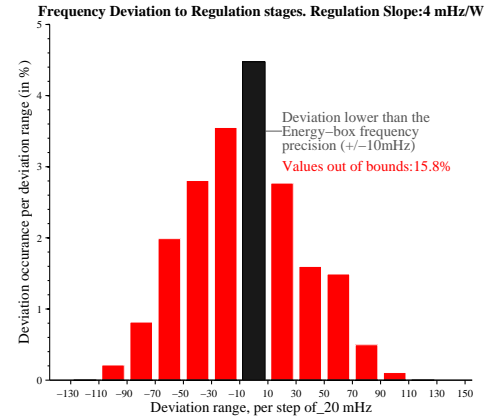


Fig. 7. Repartition of the out of bounds values, per deviation range

Unless this proportion of 15.8% of out of bounds values is not clearly explained, it stays an acceptable rate, considering first the high steady-state instability of the microgrid (Figures 6 & 7). The presence of significant reactive power on the phases to which the dispatchable loads have been connected alter maybe as well part of the frequency measurement. The quality of the material used (an Arduino UNO micro-controller) could perhaps explained also part of the deviation. Fortunately, none of these out of bounds values have been engendered by the frequency thresholds updating, which has been performed by the coordination agent each 60s during these tests. More validations on the interaction with actual FCR mechanism as well as regular load frequency schemes will be performed in the coming weeks.

## CONCLUSION

The validation of the concept on a reduced scale grid has proven significant ability to enhance the robustness of a power system. Such new paradigm in the decentralization of frequency based load shedding is mandatory in our modern power

systems including large parts of Distributed Generators. As their loss will be less and less possible, the local coordination (possible at the LV level behind one secondary substation) is fully compatible with the upcoming AMI, regardless the CEMS environment used.

#### ACKNOWLEDGMENT

This demonstration of Grenoble INP's concept has been sponsored by the European Commission and Schneider Electric within the framework of Dream FP7 European project [2].

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